# Losses of Young Anadromous Salmonids at Water Diversions on the Sacramento and Mokelumne Rivers

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## Introduction

This report describes an overview of the issues associated with the effects of unscreened diversions on anadromous salmonids in the Sacramento and Mokelumne Rivers. The geographic range of this assessment includes the main-stem Sacramento River from Keswick Dam to the northern boundary of the Sacramento-San Joaquin Delta (Delta) and the lower Mokelumne River from Camanche Dam to the eastern boundary of the Delta. Tributaries to these rivers are not discussed (including tributary water diversions positioned in close proximity to the main-stem reaches). The report provides a review of the available information pertaining to losses of anadromous salmonids to diversions in main-stem reaches of these rivers. The fish losses discussed include direct and indirect losses attributable to entrainment, predation, physical injury, and other factors associated with the diversions and diversion facilities (e.g., pumps, dams, and fish screens). This assessment includes a description of past, ongoing, and proposed actions to reduce losses of anadromous salmonids to diversions (e.g., fish screens, intake relocations, and facility modification).

## Review of Fish Losses to Diversions and Programs to Reduce Fish Losses

This section provides an historic overview of issues associated with fish losses at diversions on the Sacramento River along with past, present, and planned programs to reduce those losses. Because of the magnitude of water withdrawal, the diversions at Red Bluff Diversion Dam (RBDD), Glenn-Colusa Irrigation District (GCID), and Woodbridge Irrigation District (WID) are discussed separately in this report.

### Factors Causing Fish Losses at Diversions

The loss of young anadromous salmonids at diversions could be a result of entrainment into the diversion, predation at or near the diversion site, or physical injury associated with the diversion structures. Most investigations of fish losses at diversions have generally focused on the direct losses attributable to entrainment.

***Entrainment.*** The Resources Agency of California (RAC) reported that there are over 300 diversions on the Sacramento River between Redding and the Feather River confluence which could result in a loss of 10 million salmon annually (RAC 1989). It is estimated that approximately 1.2 million acre feet of water is diverted annually through these diversions. Most fish losses may occur between Ord Ferry and Knights Landing (Hallock 1987). The RAC suggested that this loss of juvenile salmon could translate into an annual loss of up to 100,000 adult salmon and steelhead (RAC 1989).

The most comprehensive empirical evaluation of anadromous salmonid losses entrained into irrigation diversions from the Sacramento River was conducted by the California Department of Fish and Game (CDFG) during 1953 and 1954. At that time, CDFG estimated there were more than 900 irrigation, industrial, and municipal water supply diversions upstream of the Sacramento-San Joaquin River Delta from stream sections used by anadromous salmonids within the entire Central Valley (Hallock and Van Woert 1959). CDFG reported that most of these diversions were for irrigation purposes and very few diversions were screened to prevent fish losses. During their investigation, the diversion at the Anderson-Cottonwood Irrigation District (ACID) at Redding was the only gravity-flow diversion found; all other diversions were pumped diversions. [Since their study, the diversion at RBDD became a large-scale gravity diversion on the main-stem Sacramento River beginning in August 1966 (Vogel et al. 1988)]. The 1953-1954 CDFG investigations did not include sampling at the large diversions at GCID or ACID. In 1953 there were 335 separate diversions (utilizing 448 pumps) along the 246-mile reach of the Sacramento River between Redding and Sacramento. Of these, CDFG surveyed 371 pumps at 294 separate diversions. Hallock and Van Woert (1959) concluded from intermittent sampling at 23 diversions in the Sacramento River during the 1953 irrigation season that no diversion was found to be taking young chinook salmon or steelhead in serious quantities. Results of their sampling during the entire 1954 irrigation season at nine selected diversions in the vicinity of Colusa showed that losses at individual pumps were quite small. The greatest seasonal loss found in 1954 was 2,116 fingerling salmon and 110 yearling steelhead in a 24-inch centrifugal pump (Hallock and Van Woert 1959). CDFG concluded:

> "Individually, most of the small irrigation diversions do not destroy many young salmon and steelhead. Collectively, however, they take considerable numbers."
>
> "In view of the migration time of fingerling salmon, which results in the bulk of the fish moving out of the upper river and reaching the delta by late March, and an irrigation season which does not get into full swing until late April and early May, the small losses encountered in the diversions are not surprising."
>
> "A change in agricultural practices, resulting in an earlier irrigation season, or the installation of year-round diversion canals for the transportation of water to other areas of the State, could prove disastrous to the Sacramento River salmon resources unless adequate screens were provided." (Hallock and Van Woert 1959)

In recent years, the CDFG has conducted some very limited assessment of entrainment into selected agricultural diversions on the main-stem Sacramento River. However, the sampling was too limited to provide quantitative estimates of losses and the data were not published in report format (Frank Fisher, CDFG, pers. comm.).

Additional recent data on salmon entrainment in some selected lower Sacramento River diversions have been collected but most of those data are not yet available to report (Doug Demko, S.P.

Cramer & Assoc., pers. comm.). Investigations conducted at the Reclamation District 108 intake on the lower Sacramento River estimated 10,733 young chinook salmon were entrained into this main-stem diversion from April 17 through July 24, 1993 (Cramer et al. 1994). This level of entrainment was less than the estimate of 50,106 young chinook salmon entrained into the same diversion in 1992 (Cramer and Demko 1992, as cited by Cramer et al. 1994).

*Predation.* Predation at or near water diversion facilities can be a serious problem contributing to losses of young anadromous salmonids to diversions. The potential for exacerbated levels of predation of juvenile chinook salmon by predaceous fishes has been investigated and documented at dams, such as RBDD and a number of Columbia River dams (Brown and Moyle 1981, Rieman et al. 1991, Vogel et al. 1988, Vondracek and Moyle 1983). Among the factors attributed to the elevated levels of predation on juvenile salmonids at these man-made structures has been abundant aggregations of predaceous fishes such as squawfish, perhaps due to obstruction of their migrations by the dams, concentration of the juvenile salmon in fish bypass outflows, and disorientation of juvenile salmon passing dams in the turbulent discharges of spillways, power plant outlets, and fish bypass outflows (Riemen et al. 1991, Vogel et al. 1988). The principal predators on juvenile salmon identified in these investigations have been the northern squawfish in the Columbia River and Sacramento squawfish in the Sacramento River.

The feeding behavior of squawfish is dependent on the abundance and size of squawfish, abundance and size of their prey, water temperature, physiological and health conditions, and nutritional status and time since last feeding (Vigg 1988, Vigg et al. 1991, Vondracek 1987). In his review of squawfish predation on juvenile salmonids, Garcia (1989) cited two studies of northern squawfish in the Columbia River which indicated that northern squawfish appear to have a preference for juvenile salmonids even when they are at low abundances compared to other available prey. No comparable studies were available for Sacramento squawfish to determine if they behave in a similar manner. Squawfish generally ambush their prey either solitarily from concealed locations (e.g., underwater structures such as boulders and submerged vegetation) or in large roving schools, particularly in areas where the salmon are disorientated such as at dam spills (Garcia 1989, Moyle 1976, Vogel et al. 1988). The number of juvenile salmon consumed by individual squawfish is related to the environmental factors previously mentioned and is highly correlated with the size of the squawfish (Vigg et al. 1991, Vondracek and Moyle 1983). Vondracek and Moyle (1983) found that Sacramento squawfish begin to take fish in their diets when they reach a size within the range of 10 cm to 30 cm. Cramer et al. (1992) found that only squawfish greater than 20 cm in length sampled from the GCID oxbow contained fish in their stomachs. Estimates of consumption rates of juvenile salmonids by Sacramento squawfish populations have ranged from 3 to 5.75 salmon/squawfish/day at RBDD during the month of May (Vondracek et al. 1990) to 0.02 salmon/squawfish/day in the GCID oxbow during 1991 (Cramer et al. 1992). For comparison, Vigg et al. (1991) estimated daily consumption of juvenile salmonids for northern squawfish and found it varied by season and location being highest in the turbulent spill zones of McNary Dam on the Columbia River (0.139-2.027 salmonids/squawfish/ day) and lower along the habitat of John Day Reservoir (0.043-0.251 salmonids/squawfish/day).

*Physical Injury.* Physical injury to young salmon may be an additional factor which contributes to the losses of fish at water diversion facilities. In most cases, this factor is not considered the primary factor causing the ultimate fish loss. Once a fish is diverted off the main river channel and into a diversion pipe or ditch, that fish would likely perish in the irrigation diversion system regardless of whether or not the fish sustain physical injury. The environment within irrigation systems does not provide adequate conditions to allow anadromous salmonid survival (e.g., high water temperatures, predation by piscivorous birds or predatory warm-water fish species residing in irrigation canals, dewatering, etc.).

Except for the investigations conducted at RBDD, GCID, and WID (discussed in following sections), no information was found which described potential losses of fish attributable to physical injury at main-stem diversions. In their investigations, Hallock and Van Woert (1959) describe physical injury to salmonid passing though various pumps but this factor is considered moot because the fish would be ultimately lost (with or without injury) because the fish had been diverted out of the river and into irrigation facilities. The potential does exist for some fish losses to occur as a result of physical injury on trash racks installed on water diversion intakes. Also, fish losses at existing fish screens may occur if fish are impinged on the fish screens or injured during passage through the fish bypass system. In some instances, existing fish screens which do not provide adequate fish protection are overlooked for renovation because localities where no fish screens are present generally receive highest priority (Vogel 1993a).

**Past Programs to Reduce Fish Losses at Diversions**

Fish screen requirements were originally specified in the California Penal Code in 1891 although there was little effort to implement those requirements prior to 1912 (Quelvog 1981). In 1912, a Department of Screens and Ladders was established by the California Fish and Game Commission and by 1919 over 500 fish screens were reported in operation (CDFG 1919, as cited by Quelvog 1981). Although early screen installations (essentially parallel bar racks) and their maintenance were the diverter's responsibility, legislation in 1933 required the Division of Fish and Game to pay half of the original screen installation cost; in 1965 the CDFG was responsible for all costs for diversions less than 250 cubic feet per second (cfs) (Quelvog 1981). California Fish and Game Code Sections 5980-5993, 6020-6028, and 6100 presently provide the authority for CDFG to require fish screens and adequate fish bypass flows (RAC 1989). Since the early portion of the century until the present there have been numerous improvements in the types of fish screens used. Most of these modifications were associated with improved protection for the early life phases of anadromous salmonids and reduced maintenance requirements for the screens (Quelvog 1981).

At the present time, there are very few fish screens in operation on the main-stem Sacramento River (Phil Warner, CDFG, pers. comm.; Nick Villa, CDFG, pers. comm.). In 1981, Quelvog

(1981) reported only three fish screens in operation on the main-stem Sacramento River. These were located at the ACID diversion (max. 400 cfs) (installed 1969), the Tehama-Colusa Canal diversion (max. 2,400 cfs) (installed 1966), and the GCID diversion (max. 2,700 cfs) (installed 1972). In 1990, the CDFG stated that only four diversions on the Sacramento River had fish screens of which only two were considered adequate (CDFG 1990). The City of Redding municipal water intake has a screen on their main-stem Sacramento River diversion but the mesh size on the screen does not meet CDFG criteria. However, sampling by the CDFG two years ago did not reveal any salmonid entrainment at this diversion; therefore, the diversion is not considered a high priority for retrofit at the present time (Phil Warner, CDFG, pers. comm.). The Bella Vista Water District intake on the Sacramento River at Redding possesses a vertical traveling fish screen but the CDFG is concerned over the adequacy of the seals on the screen and the fact that the screen is set back a short distance from the river with no fish bypass (Phil Warner, CDFG, pers. comm.).

The ACID diversion at Redding utilizes a gravity-flow diversion off a 450-foot flashboard dam which was originally constructed in 1917 (USBR 1992). Much of the original focus of concern over fishery resource impacts caused by ACID operations was oriented toward severe upstream migrant fish passage problems. It is believed that in the early years of ACID operations (prior to the installation of fishways), the dam blocked nearly all of upstream migrating salmon enroute to their spawning grounds (McGregor 1922). The flashboards on the dam are generally in place from April to October (RAC 1989). Concern has been expressed that the fish passage facilities on the dam are inefficient for fish passage (CDFG 1990). No information was found to indicate if any investigations have been conducted to determine if physical injury to young salmon passing over the dam occurs or if significant predation takes place immediately downstream of the dam or the fish screen bypass outfall. CDFG is confident that the fish screen installed at the ACID diversion in 1969 and subsequently modified is adequate to prevent entrainment and impingement (USBR 1992).

The ACID operates a second diversion downstream of Redding near the Bonnyview Bridge. This diversion was unscreened until recently when the National Marine Fisheries Service (NMFS) took enforcement action under the Federal Endangered Species Act against ACID (NMFS 1993). A fine of $700,00 was originally levied against ACID in 1991 and the District subsequently installed screens on their three water intakes during the summer of 1992 to prevent young salmon from entering their irrigation pump intakes (USBR 1992). Underwater inspections by NMFS SCUBA divers indicated the screens were performing satisfactorily for fish protection (Larry Preston, ACID, pers. comm.).

Details on the fish protection systems at RBDD, GCID, and WID and fish screens installed within the past year are provided in following sections.

## Present and Future Programs to Reduce Fish Losses at Diversions

There are a variety of programs planned or underway by State and Federal agencies to reduce fish losses to river diversions. The following are summaries of those programs.

*U.S. Fish and Wildlife Service (USFWS) and U.S. Bureau of Reclamation (USBR).* As a portion of the Central Valley Project Improvement Act (CVPIA) [(3406 (b)(21)] (PL102-575), the U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation are developing a joint program for avoiding losses of anadromous fish at unscreened diversions in the Central Valley. Estimates to screen all water diversions in the Central Valley and Delta have ranged up to $1 billion (Hayes 1994). The USFWS has the lead for this program (Roger Guinee, USFWS, pers. comm.). The following information on this program was provided by Ron Brockman, USBR, Sacramento.

In FY 1994, USBR and USFWS initiated efforts to assist the State of California to develop a program for avoiding losses of juvenile anadromous fish resulting from unscreened or inadequately screened diversions on the Sacramento and San Joaquin River, their tributaries, the Delta, and Suisun Marsh. Public meetings will be held with interest groups identified for this action element to discuss issues, concepts, and elements which should be included in a Framework/Implementation Plan. Such a plan will address overall program format, inventory needs, application process, public involvement needs, guidelines and criteria for selection of diversion sites, monitoring requirements, regulatory agency permits and approvals, environmental documentation (NEPA/CEQA, ESA/CESA), and reporting needs. An interagency fishery/engineering technical workgroup will be assigned much of the responsibility for developing the draft plan. Currently project leaders from USBR and USFWS are working with CDFG to develop an agreement defining the State's unscreened diversion program and how the Department of Interior can assist the State as prescribed in the CVPIA.

The program will consist of a long-term program as well as a short-term Accelerated Implementation Program. The short-term program will allow worthwhile screening projects to be implemented under a short time frame as long as necessary regulatory permits and approvals can be obtained expeditiously. Information obtained from such projects will be incorporated into the final Plan and should assist in implementing other projects. Selection criteria for the short-term program have been established with the assistance of the interagency workgroup and the first positive barrier screen has been installed at the Maxwell Irrigation District's diversion on the Sacramento River. Cost to the Federal government for this screen was $400,000. The workgroup is currently developing a list of candidate project sites to be considered for the Accelerated Implementation Program until the Plan for the long-term program can be developed.

Specific tasks for this program include the following:

- Organizing and preparing a program framework
- Initiating and continuing public involvement program
    - selection criteria
    - candidate sites
    - plan preparation
- Developing a Memorandum of Agreement with CDFG
- Developing a Memorandum of Agreement with NMFS
- Establishing an Interagency technical team
- Developing and implementing a short-term accelerated program
- Preparing a long-term implementation plan
- Implementing the long-term plan

Selection criteria for sites to be chosen for the short-term accelerated program are as follows:

- Potential sites (not specifically identified in CVPIA) that when treated will meet the intent of the CVPIA.
- Sites consistent with the fish screening guidelines, priorities and policies being developed by the federal and state fishery agencies (CDFG, NMFS, USFWS).
- Sites that, if treated, will benefit State and federally-listed threatened and endangered species.
- Sites for which the engineering design and environmental permitting process is complete or nearly complete.
- Sites for which non-federal funding is available and which will cover at least 50 percent of all of the estimated costs of installing a screen project (including planning, design, construction, installation, monitoring and evaluation).
- Sites that demonstrate technology that can be replicated at other sites with similar problems.
- Sites where the landowner has agreed to allow access for monitoring and evaluation and has made a commitment to long-term operation and maintenance costs.

In the past two years, the USBR completed a pilot demonstration program to install fish screens at three sites on the Sacramento River to eliminate entrainment of young salmon into unscreened agricultural diversions. The program was implemented in accordance with the NMFS Biological Opinion concerning Central Valley Project Operations effects on winter-run chinook salmon which directed USBR to "... develop and implement a demonstration screening program designed to advance the state-of-the-art positive screening barrier technology at small unscreened diversions along the Sacramento River ..." (Spencer Hovekamp, USBR, pers. comm.).

The three sites chosen for the fish screen demonstration projects were on the Sacramento River at the Pelger Mutual Water Company diversion, Wilson Ranch (Newhall), and the Cannell Ranch.

The Pelger diversion, located at Sacramento River mile 111.7, was screened with a Lakos-Plum Creek self-cleaning pump intake screen to prevent fish entrainment. This diversion has a maximum capacity of 50 cfs through two side-by-side slant pumps. The Wilson Ranch diversion, is located near river mile 203 in an oxbow on the Sacramento River and has a capacity of 29 cfs through three slant pumps. The diversion was recently screened with a flat-plat screen installed and removed annually at the entrance to the oxbow approximately 4,000 feet from the pumps. The Cannel diversion is located on the Sacramento River at river mile 160.4 and has a maximum capacity of approximately 27 cfs through a centrifugal pump. This diversion is screened with a Lakos-Plum Creek screen. (Spencer Hovekamp, USBR, pers. comm.)

The U.S. Bureau of Reclamation has also initiated a project to develop a design for screens to have broad application on Sacramento River diversions. The following summary of this project is based on personal communication with Greg O'Haver, an engineer with the USBR at Shasta Dam. Presently, the USBR is in the process of modeling and testing an underwater, stream bottom, retrievable fish screen device. A one-quarter-scale model of the screen is being tested at the USBR's hydraulic laboratory in Denver. The intent of this project is to develop a fish screen which can be manufactured in mass production and be universally utilized under a wide range of riverine conditions. The device would possess flat stainless-steel wedge-wire screen (3/32-inch opening and 50 percent open space) on the top. Two sizes of the screen type would be manufactured: one that could screen up to 100 cfs and the other for screening up to 25 cfs. The dimensions of the largest screen are estimated at 25 feet long by 12 feet wide by 6 feet high in a rectangular box-type configuration. The wedge-wire would be positioned perpendicular to the river flow. The screen approach velocity is designed for 0.33 ft/s or less with a run-of-the-river sweeping flow over the screen estimated at greater than 1 feet per second. There would be no structural fish bypass because the river would serve as the fish bypass. The screen device would be placed directly on the riverbed over the intake to a river diversion intake pipe. The entire screen would be cleaned using an air purge mechanism powered by gasoline or electric power and operated on a timer. Baffles are positioned inside the screen to ensure uniformity in screen approach velocity and air purge. The upstream and downstream portions of the device would be streamlined to provide reasonably uniform hydraulic conditions and reduce potential predatory fish habitat. Most components of the device would be made of light-weight materials such as plastic, fiberglass, and PVC. The screen device would be easily and quickly retrievable for inspection or removal such as prior to high flow events. Internal air tanks and a cable mechanism would be used to retrieve and place the device over the diversion intake. Estimated cost of the screening device once it is produced in large quantities is $1000/cfs or less.

***California Department of Fish and Game***. CDFG has developed a Statewide Fish Screening Policy which provides guidance on how the agency deals with screening water diversions. The policy, approved by the Director of CDFG on March 9, 1994 clarifies the administrative regulations and authorities governing the enforcement and implementation of screening diversions (Hayes 1994). The policy is structured to comply with existing fish screening statutes, the National Environmental Policy Act, the California Environmental Quality Act, the Federal

Endangered Species Act, the California Endangered Species Act, and court decisions in place at the time the policy was adopted (CDFG 1994). The CDFG also has developed general fish screening criteria which provides technical information for fish screens including placement of the structure, approach velocity, sweeping velocity, screen openings, and screen construction. These criteria were developed pursuant to Fish and Game Code Sections 1600, 5900, and 6100 (CDFG 1993).

CDFG is currently developing a comprehensive plan for screening unscreened riverine diversions (Paul Raquel, CDFG, pers. comm.). A June 6, 1994 edition of CDFG's Fish Screen Action Plan identifies diversions by the following priorities in the plan:

***Priority One: Diversions Located Within the Critical Habitat of a Federally Listed Species or the Essential Habitat of a State Listed Species***

Diversions serving lands owned and/or operated by CDFG
    - Diversions owned and operated by CDFG
    - Private diversions serving lands owned and operated by CDFG
- Diversions larger than 250 cfs capacity
- Diversions of 250 cfs or less capacity

***Priority Two: Diversions Located Within the Habitat of Salmon, Steelhead, and Anadromous Fishes***

- Diversions serving lands owned and/or operated by CDFG
    - Diversions owned and operated by CDFG
    - Private diversions serving lands owned and operated by CDFG
- Privately owned diversions larger than 250 cfs capacity
- Privately owned diversions of 250 cfs or less capacity

***Priority Three: Diversions in Other Inland Waters of the State***

***Priority Four: Other Diversions in Coastal Waters of the State***

This CDFG Fish Screen Action Plan is not considered final because it is expected to be revised and updated (Dan Odenweller, CDFG, pers. comm.).

The CDFG has a project underway to inventory the main-stem Sacramento River to locate individual water diversions (Phil Warner, CDFG, pers. comm.). For example, surveys conducted on the lower portion of the Sacramento River identified 58 unscreened diversions between the confluences of the Feather and American Rivers and 316 unscreened diversions between the American River confluence and the Delta Cross Channel (CDFG 1994).

***National Marine Fisheries Service.*** NMFS is currently considering proposing regulations that would establish requirements of screening water diversions from the Sacramento River and Delta to protect the endangered winter-run chinook salmon (NMFS 1993). In addition to requesting public comment on the proposed rulemaking, NMFS also solicited specific information on the following:

- The numbers, types, and sizes of unscreened and screened diversions in the Sacramento River and Delta.
- The magnitude of losses of winter-run chinook salmon and other fish species caused by unscreened diversions in the Sacramento River and Delta.
- The feasibility of installing positive-barrier screens or other fish-deterrent devices to reduce these losses.
- The estimated costs of screen design, installation, maintenance and evaluation.
- The availability of funding mechanisms for screen design, installation, maintenance, and evaluation.
- The availability and feasibility of alternative management options that may reduce losses from unscreened diversions such as seasonal pumping restrictions, monitoring requirements, or alternative water supplies. (NMFS 1993)

NMFS is currently reviewing public responses to the proposal and will attempt to coordinate proposed rules with the CVPIA fish screen program (Gary Stern, NMFS, pers. comm.).

## Red Bluff Diversion Dam

The Red Bluff Diversion Dam on the upper Sacramento River near Red Bluff went into operation in August 1966. The purpose of the dam was to divert water off the Sacramento River into the Tehama-Colusa Canal and Corning Canal. The Corning Canal is used only for agriculture whereas the Tehama-Colusa Canal was originally used to convey water for agriculture, wildlife refuges, and the Tehama-Colusa Fish Facilities (Vogel et al. 1988). During the late 1980s, the Tehama-Colusa Fish Facilities were "mothballed" (i.e., placed into a non-fish-production mode) (Vogel 1989).

Fishery resource investigations conducted at RBDD during the 1970s and 1980s identified severe upstream and downstream anadromous salmonid passage problems at the dam (Vogel et al. 1988). CDFG study results indicated that substantial losses of juvenile salmonids were attributable to the dam's operations for water diversions into the adjoining canals (Hall 1977, Hallock 1980, Hallock 1983). For example, a CDFG study conducted during the 1970s suggested that losses of young salmon could be in the range of 29 to 77 percent (Hallock 1983). Largely as a result of these and other prior investigations, the USFWS began intensive studies in the early 1980s to determine specific sources of fish mortality at the water diversion facilities.

These research projects evaluated:

- Fish losses attributable to entrainment into the Tehama-Colusa and Corning Canals.
- Direct injury to fish as a result of passing under the dam gates or through the fish louver bypass facility.
- Delay of fish in the reservoir upstream of the dam which could cause the natural fish emigration to be asynchronous with normal smoltification and with seasonal cycles of water temperatures and food production in the lower river or ocean.
- Predation on young salmonids resulting from ideal conditions created by RBDD for piscivorous fishes and birds in the reservoir upstream of the dam or immediately downstream of the dam. (Vogel et al. 1988)

The USFWS studies concluded that predation and entrainment were the most severe problems affecting young salmonids at the main-stem water diversion facility. Predation losses were found to be as high as 50 percent and entrainment losses ranged from 200,000 to 600,000 fish annually. As a result, a new state-of-the-art rotary drum fish screening facility and new fish bypass system for the diversion were recommended and installed to reduce those losses. The new screens went into operation during the spring of 1990 (Vogel et al. 1990).

The USFWS has initiated several investigations to assess the efficacy of the new fish screening facility installed at RBDD. In 1993, the USFWS performed tests to determine if physical injury to young salmon was occurring as the fish passed through the new fish bypass system. Of 19 tests conducted, no significant mortality attributable to physical injury was observed for test groups of juvenile salmon released into the bypass system and subsequently recaptured and held for 48 hours. However, descaling on fish released through the bypass system appeared higher than control groups of fish during their tests (Big Eagle et al. 1993). To evaluate entrainment, the USFWS operated fyke nets in the Tehama-Colusa Canal downstream of the new screens and estimated that 33 young salmon were entrained into the canal during the entire 1993 irrigation season. The USFWS concluded that the new screens were operating very efficiently in screening juvenile salmonids in diversions flows up to 2,300 cfs (Johnson and Croci 1994). In addition to the biological evaluations, the USBR performed hydraulic evaluations at the screens during 1993 with diversion flows in the range of 2,300 cfs to 2,500 cfs (USFWS 1993).

To assist in protecting the endangered winter-run chinook salmon, the USBR has been raising the RBDD gates during the non-irrigation season (November 1 through April 30) each year since the late 1980s. This action was implemented to provide unimpeded upstream and downstream passage for anadromous salmonids. A NMFS Biological Opinion concerning USBR's operation of the Central Valley Project now requires that the RBDD gates be removed from September 15 through May 14 of each year (USBR 1993).

In a related measure to raising the RBDD gates each year, the USBR (in concert with the fishery resource agencies) has designed and is nearing completion of a pilot research riverine pumping facility to provide additional water into the Tehama-Colusa and Corning Canals during the gates-raised period. The facility will be evaluated on its merits for potential fish protection while concurrently providing water supplies for agriculture and wildlife refuges. The research facility consists of two closed Archimedes screw pumps (100 cfs each) and one helical pump (100 cfs). An additional pump of either type may be added in the future (USBR 1993). Total cost of the facility is $11 million (Hayes 1994).

A variety of evaluations of the new pumping plant are planned over the next three to five years. These include assessments of pump/sump designs, trash rack configurations, and hydraulics. Biological evaluations will include tests on potential fish injury, pump mortality, stress, movement/delay, and predation susceptibility. Total costs of the evaluations are estimated at $2 million (Hayes 1994). The following describes the individual items planned for evaluation and the estimated study intervals for each study item (USBR 1994).

| Study Interval | Subject of Study |
|---|---|
| January 1995 through April 1997 | Direct mortality and injury to young chinook salmon subjected to passage through experimental pumps |
| January 1995 through December 1998 | Seasonal numbers, annual numbers, condition, and viability of young chinook salmon entrained by experimental pumps |
| January 1995 through March 1996 | Efficiency of recovery of young chinook salmon in Pumping Plant holding tanks following passage through experimental pumps |
| January 1995 through September 1996 | Residence times, and viability and condition of young chinook salmon subjected to passage through various portions of the Research Pumping Plant (i.e., intake bay through pumps, intake bay through screens, intake bay through holding tanks, intake bay through bypass lines to the river) |
| November 1994 through November 1997 | Underwater video and hydroacoustic detection of movements and behavior of young chinook salmon in the vicinity of intake structures for experimental groups |

| | |
|---|---|
| January 1996 through June 1997 | Predator-prey interactions between young salmon and squawfish following passage of chinook through experimental pumps |
| May 1995 through November 1998 | Colonization of the intake sump of the Research Pumping Plant by predators and, if required, development methods for their control |
| February 1996 through August 1997 | Pumping Plant Entrainment of early life stages of Sacramento River fishes and assessment of impacts on their populations |

## Glenn-Colusa Irrigation District

The history of fish protection efforts at the Glenn-Colusa Irrigation District's (GCID) Sacramento River pumped diversion dates back to the summer of 1929. Phillips (1931), as reviewed by Ward (1989), reported the results of the first fisheries monitoring investigation which consisted of fish sampling in the diversion canal below the old pumping plant. They found that approximately 53 percent of the fishes entrained into the diversion during the months of April through August were juvenile chinook salmon. It was also found that more than half of these salmon were injured or killed as a result of entrainment through the pumps. Nets operated in the irrigation canal between April 18 and August 20, 1929, took large numbers of game fish, including salmon and steelhead; substantial numbers of salmon were lost even in late June (Hallock and Van Woert 1959). Based on these findings and a court ruling in 1931, a fish screening device was installed in 1935 to reduce fish entrainment at the old pump station.

The old fish screen was replaced in 1972 with a rotary drum screen facility by the California Department of Fish and Game. Shortly after construction of these fish screens, CDFG conducted an evaluation of the efficacy of this facility in 1974 and 1975 (Decoto 1978, 1979). These studies evaluated fingerling salmon passage through the fish screen bypasses and through culverts in the earthen dam downstream from the fish screen, as well as, juvenile salmon entrainment through the drum screen structure into the pump forebay and diversion canal. Decoto concluded that the fish screen bypasses were not functioning efficiently in terms of entrance size and entrance velocity. More fingerling salmon were found to pass through the culverts in the earthen dam than through the fish screen bypasses and both fry and smolt sized salmon were found to be entrained past the fish screens. But because of limitations of his experimental design, Decoto was unable to account for the fate of 66 to 82 percent of the marked experimental fish that he had released for his studies. He hypothesized that:

"(1) They returned upstream and out to the main river channel,
(2) they were eaten by predators,
(3) they escaped through the drum screens via the screen mesh and seals, and
(4) combinations of the first three."

The original problems with CDFG's rotary drum screen facility were exacerbated over the last two decades by considerable stream bed degradation in the main river near the oxbow intake channel. This resulted in suboptimal fish screening and passage conditions due to reduced water surface elevations at the fish screens and reduced bypass flow velocities in the oxbow returning to the main river. In response to these problems with fish screen performance, CDFG installed a fyke trap near the center of the fish screen facility in 1985 to serve as a temporary fish salvage measure. The fish trap was operated nearly continuously during the pumping season at the site since May 1985 and was used for fish salvage and for long-term monitoring of fish occurrence and relative abundance at the site. However, the CDFG trap was not effective for monitoring population levels of fishes occurring in the oxbow because trap efficiency was calibrated for only one set of pumping rate, river flow, and environmental conditions shortly after its installation in May 1985 (Ward 1989).

Based on results from the previously mentioned studies at dams and on a reputation of squawfish for adapting to and exploiting man-made habitat alterations to its advantage, predation by squawfish on juvenile salmon has been hypothesized to be potentially problematic at the GCID intake channel (Garcia 1989). Investigations conducted by GCID's fishery consultant and electrofishing surveys conducted by the CDFG in the GCID oxbow during 1990 and 1991 determined that the abundance of squawfish on any one day was relatively low and appeared to be quite mobile (Cramer et al. 1990, 1992). Cramer et al. (1990) generated an estimate of 306 squawfish inhabiting the oxbow in the vicinity of the fish screens during a period in June and July 1990. During 1991, additional study work on squawfish in the oxbow indicated that the population density remained considerably lower than observed at dams where predation problems for juvenile salmon have been documented (Cramer et al. 1992). Additionally, the electrofishing surveys revealed that adult squawfish (>20 cm), those large enough to eat juvenile salmon, comprised 58% of the total squawfish population inhabiting the oxbow. So, only a portion of the squawfish population inhabiting the oxbow at any one time was capable of preying on juvenile salmon.

Ward (1989) reviewed the past fishery studies conducted at the GCID diversion and compiled information and data collected at CDFG's fish salvage operation between 1985 and 1989. He concluded that between 400,000 and 10 million juvenile salmon annually may have been lost at the diversion with the CDFG fish screen in place between 1972 and 1989. The losses were not specifically attributed to any one particular mortality factor but were assumed to be affected by a combination of suspected predator congregations near the fish screens and in the oxbow, impingement on the fish screens, and entrainment through the screen facility. Ward's analysis was based on historical river flow and diversion information, incidental recoveries of marked salmon at the CDFG trap from Coleman National Fish Hatchery smolt releases, and assumptions concerning the behavior and spatial distributions of downstream migrant salmon passing the vicinity of the oxbow intake channel. No direct experimentation to validate assumptions and approaches were conducted for this analysis.

As part of a 1987 Memorandum of Understanding between GCID and CDFG, GCID initiated evaluations during 1990 intended to provide biological information useful for defining and designing solutions to the fish passage and water supply problems at the pump station. Specific causes of juvenile salmon losses at the fish screens had never been thoroughly investigated in previous studies. However, an understanding of the site-specific causes of fish loss was essential for design of a long-term fish protection solution for this site. The evaluations attempted to: 1) identify and quantify factors affecting the diversion rate and total loss of downstream migrant juvenile salmon passing into the GCID intake channel from the main river channel; and 2) identify and quantify the relative importance of specific factors affecting mortality of juvenile salmon once they enter the intake oxbow channel (e.g., impingement on the fish screens, entrainment through the fish screen structure, and predation on juvenile salmon in the intake and bypass channels).

Cramer et al. (1990, 1992) reported the results of mark-recapture fish diversion and survival studies conducted as part of GCID's biological evaluations. Contrary to previous assumptions about the spatial distribution of downstream migrant juvenile salmon relative to river flow, these evaluations indicated that juvenile salmon at this site were not diverted in direct proportion to the quantity of river flow diverted, but appeared to be diverted at a rate lower than the proportion of river flow diverted. These studies also revealed that some marked experimental fish were swimming upstream and out of the oxbow. This finding confirmed a hypothesis promoted by Decoto (1978) and called into question the interpretations and assumptions that have been developed based on previous mark-recapture evaluations at the site (i.e., Decoto 1978, Ward 1989). Predation on juvenile salmonids in the oxbow was also assessed during the summer season in 1991 and predator population levels and consumption of young salmon were found to be low. However, because no data on predation were collected during the spring season, a time when large numbers of young salmon are present in the oxbow, knowledge of overall impacts of predators on salmon in the oxbow remains incomplete.

Underwater inspections and videography of the screens and underwater observations of fish behavior were conducted by fisheries scientists during 1990, 1991, and 1992. These inspections and direct observations led to the formulation of a hypothesis that fish losses at the site were exacerbated by the creation of fish "entrapment zones" beneath the lower portion of the rotary drum screen bays. Adverse physical and biological conditions in the entrapment zones were suggested as factors which may cause increased incidence of predation, entrainment, and impingement (physical injury) at the screens.

During 1991 and 1992, a proposal was circulated by GCID to seal off the bottom portion of the entrapment zones with flat-plate screens to exclude fish, yet allow water flow through the screens. In 1992, the proposal was modified by GCID to place flat-plate screens across the entire trash rack in front of the existing screens to exclude fish from entering the area between the trash racks and the rotary drum screens. This proposal was presented as a suggested interim measure to reduce mortality of fish at the site until a long-term solution could be developed and placed into operation. The initial installation of the new flat-plate screens was completed in August 1993.

In 1994, biological and hydraulic evaluations of the interim fish screens at GCID were initiated. The hydraulic evaluations were initiated to quantitatively assess the hydraulic characteristics of the interim screens. The biological investigations were performed for the following purposes:

1) To provide an evaluation of the benefits for passage of fry and larger juvenile anadromous salmonids with installation of the new flat-plate screens, and

2) To develop information on specific attributes and biological performance features of the new flat-plate fish screen that will be useful for evaluating proposed fish screen designs and for identifying a long-term solution for fish protection at the GCID pumping station.

The field-portion of the biological investigations was completed by July 15, 1994 and results were presented in a report completed in January 1995. Results of the hydraulic evaluations of the facility were given in a report completed in November 1994.

For the past several years, GCID has been working with State and Federal agencies to identify a permanent solution to the fishery resource problems at the District's Sacramento River pumping station. In August 1991, the U.S. Department of Justice, at the request of NMFS, obtained a Federal court order to enjoin GCID from operating the pumping station in violation of the Federal Endangered Species Act. This action resulted in a court order which restricts GCID's operations to minimize impacts on winter-run chinook salmon. As a result, GCID agreed to pursue a long-term screening solution that implements the best available proven technology to protect juvenile winter-run chinook salmon from entrainment and predation at the diversion site (NMFS 1993). A steering committee composed of Federal and State representatives and GCID has been working to develop alternatives to be addressed in the EIR/EIS and Feasibility Report for the project. Alternatives under consideration include modifying the existing screening structure, relocating the intake, constructing new screens, restoring the gradient of the Sacramento River in the vicinity of the intake, or a combination of these alternatives. The Feasibility Report and administrative draft EIR/EIS are presently in the agency/steering committee review stage. Public review and a Record of Decision (ROD) by the Department of the Interior/USBR are scheduled during 1995. Until receipt of the ROD, concurrent preliminary design and planning will take place under USBR direction pursuant to Title 34 CVPIA (pp. 402-575). The final fish screening project is expected to be complete by 1997. (Ben Pennock, GCID, pers. comm.)

## Mokelumne River

On the lower Mokelumne River between Camanche Dam and the Delta, the only fish screens in operation at the present time are located at the Woodbridge Irrigation District's intake at Woodbridge and the two intakes for the North San Joaquin Water District (Nick Villa, CDFG, pers. comm.). In 1981, Quelvog (1981) reported only two screened diversions on the lower Mokelumne River: Woodbridge (max. 450 cfs) (installed 1968) and Lockford (max. 35 cfs) (installed 1958). Fisher (1976) reported that the WID fish screens were constructed in 1967 and became operational on April 3, 1968. The two North San Joaquin Water Conservation District's intakes (located upstream of WID) possess only limited perforated plate screens manually put in place each irrigation season with no mechanical cleaning device (Nick Villa, CDFG, pers. comm.). CDFG's Fish Screen Action Plan identifies these two diversions as having a capacity of approximately 30 cfs each (CDFG 1994).

**Woodbridge Irrigation District**

In 1955, the CDFG conducted some limited sampling of young salmon losses into the Woodbridge Irrigation District's gravity-flow diversion on the lower Mokelumne River during the early portion of the irrigation season. The sampling was discontinued because of low water velocities in the irrigation canal which rendered the sampling gear ineffective. The sampling was conducted from March 27 to May 7, 1955, and only three salmon were captured during 326 total hours of netting (Hallock and Van Woert 1959).

In April and May 1974, the CDFG performed a limited evaluation of entrainment into the WID canal past one of the rotary drum fish screens. Two fyke nets were fished behind one of the seven screen bays to evaluate entrainment past the screen. Twenty-two chinook salmon and 1 steelhead fry were collected behind the screen over 51 days of monitoring. Fisher (1976) hypothesized that these fish got past the screens by entrainment through the screen mesh.

In 1992, the East Bay Municipal Utility District conducted an assessment of the fish passage facilities at Woodbridge Dam and the WID fish screens. Vogel (1992) found numerous gaps at the base of each of the seven fish screens in the concrete keyway slots where the fish screens are slid into place. Vogel (1992) suggested that the fish entrainment which Fisher (1976) reported may have been attributable to entrainment through the keyway slots instead of the screen mesh. This assessment pointed out numerous other features of the fish facility which may affect young salmon; recommendations were provided to improve fish passage. Vogel (1992) also provided an assessment of fish passage issues associated with the Woodbridge Dam upon which the WID depends to obtain gravity flow of water into the irrigation canal. Included among these were potential problems for young salmon caused by possible predation in the impoundment behind the dam, downstream of the dam, and possible physical injury to fish passing over the dam or through the fish screen bypass.

Subsequent testing conducted at Woodbridge Dam in the spring of 1993 confirmed that measurable levels of losses attributable to physical injury to fish passing over the dam can occur. Eight of 14 tests demonstrated statistically significant higher mortality in test fish released over the dam as compared to control fish. The studies suggested that mortality attributable to physical injury could be in the range of approximately 6 to 11 percent (Vogel and Marine 1994). Observations at the dam during the spring of 1993 and 1994 noted that predation on young salmon passing over the dam does occur by striped bass and squawfish.

## Considerations on Methodologies to Evaluate Fish Losses to Diversions

A review of the available information reveals that there are insufficient data to reasonably or accurately quantify the potential losses of young anadromous salmonids at most diversions under existing conditions or to quantify the benefits to the fish populations from screening riverine diversions. The Resources Agency of California reported:

> "Although some information exists on water diversion locations and pumping capacities, detailed data such as diversion construction and intake design/location of each are lacking or not readily available. Studies are needed to identify diversions that significantly affect the fishery and to determine the cost of work required to effectively screen each diversion." (RAC 1989)

The Resources Agency of California identified the need to reduce the mortality of salmonids at unscreened diversions on the Sacramento River (from Keswick Dam to the Feather River confluence) as the 10th priority among 20 fishery resource-related action items for the upper Sacramento River. The Upper Sacramento River Fisheries and Riparian Habitat Management Plan identified the following solutions to the problem of unscreened diversions:

1) Define the minimum size of diversion that significantly affects the fishery and inventory all larger diversions of water from the Sacramento River between Redding and the mouth of the Feather River. This inventory should describe each diversion in detail.

2) The Corps of Engineers should inventory each diversion currently under its permit. If a screen is a condition of the Corps' permit, require full installation and maintenance compliance to meet screening requirements of fishery management agencies. Interagency cooperation is essential to accomplish this task.

3) Require screening and screen maintenance on all diversions on the Sacramento River that significantly impact the fishery and develop a process for funding this work.

4) Obtain funding to design and install screens at private diversions currently not under permit from the Corps of Engineers.

5) Adequate funds should be appropriated to conduct comprehensive fish screen design studies. These studies should be performed by a qualified independent research organization, such as a major laboratory specializing in fish swimming energetics, metabolism, stress, and predation response. A technical advisory group should be formed to review this work. This group should include engineers, biologists, and management specialists knowledgeable in fish behavior.

   Hydraulic parameters addressed by the study should include flow uniformity under varied





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stage and volume, erosion, deposition, and screen fouling. Mechanical parameters should include dependable operation and cleaning systems, with system bypass or removal options in case of screen failure. Future screen designs should be physically modeled to assure their performance meets the specified requirements prior to construction and/or reconstruction of major new facilities.

Alternative fish protection methods also should be considered. Innovative techniques should be studied in an effort to minimize fish losses and maximize screening efficiency in a cost-effective manner." (RAC 1989)

In the April 1990 "Central Valley Salmon and Steelhead Restoration and Enhancement Plan", the CDFG made the following recommendation to alleviate fish losses at unscreened diversions on the Sacramento River:

"Interagency coordination and funding should be established to inventory the water diversions, including their design, location, and construction. A uniform screening policy and specification should be established among agencies and the DFG. Installation or reconstruction of screens should be accomplished at private diversions with assistance from public funds. The diversions currently under permit with the U.S. Army Corps of Engineers (USCOE) should require full installation and maintenance of facilities to comply with adopted screening specifications." (CDFG 1990)

Only one document was found which estimated the total loss of young chinook salmon into unscreened diversions on the Sacramento River. The Upper Sacramento River Fisheries and Riparian Habitat Management Plan prepared in January 1989 stated:

"The effects of over 300 unscreened diversions on the fishery are not accurately known. However, based on estimates prepared for Glenn-Colusa Irrigation District, the annual diversion of approximately 1.2 million acre-feet of water suggests that the losses may exceed 10 million juvenile salmonids each year. This represents a loss of up to 100,000 adult salmon and steelhead." (RAC 1989)

Although comprehensive empirical data and information are lacking to reasonably quantify fish losses and the benefits derived from screening, there are a wide variety of factors which can be qualitatively described in terms of how those factors can influence the loss of fish at diversions and how alleviating or incorporating these factors into fish screening programs could help assess the benefits. Each of these factors is described in the following sections. CDFG has pointed out that "the magnitude of fish losses at any given diversion depends on a complicated set of relationships which include the size of the fish, the timing of their migration, and the volume and velocity of the diversion in relation to the flow continuing past the diversion." (CDFG 1990). In examining the topic of main-stem rearing habitat and the downstream migration of young salmon and associated issues with diversions, there are numerous factors which should be considered in evaluating potential benefits of fish screening programs. The following factors are not listed by priority because each diversion has site-specific characteristics which influence the diversion's effects on fish. A particular factor which may have an overriding influence at one diversion site could have a negligible influence at another diversion site.

**Localized Configuration of the Diversion Intake**

Size and type of pump, depth of intake, distance between intake and the river bank, angle at which the intake pipe entered the water, velocity of flow past the intake, and size and type of intake screen, and position of the intakes were considered as important factors by Hallock and Van Woert (1959) which would influence fish losses to diversions. Researchers have provided useful information which demonstrates that juvenile salmon can exhibit markedly different behavior in the vicinity of trashracks and among variations in trashrack spacing (Reading 1982, Hanson and Li 1983, Kano 1987). These factors can significantly influence the susceptibility of young salmon to entrainment or predation at the diversion site.

**Orientation of the Diversion Intake in the River Channel**

Figure 1 provides some example orientations of water diversion intakes in a riverine channel. Each of these locations may make the intakes a greater hazard (or alternatively, a lesser hazard) to young salmon depending on site-specific considerations. In most instances, there has been insufficient research to determine specific "susceptibility hazard factors" to salmon for these various locations. However, it is widely recognized that fish diverted into an intake channel with no bypass flow back to the river would be unlikely to survive. Downstream migrants following flow under these conditions would have to swim back upstream out of the intake channel to escape hazards (e.g., predators, entrainment). Upstream migration of downstream migrant fish would be an uncharacteristic behavior response.

**Salmon Distribution in the Water Column and Across the River Channel**

Sampling by the U.S. Fish and Wildlife Service between 1949 and 1953 in the Sacramento River near Red Bluff demonstrated that during periods of normal stream flow[1] fingerling chinook salmon migrated downstream at depths varying from the surface to four feet, with the greatest numbers at two to four feet below the surface. The USFWS also found that juvenile salmon migrated downstream fairly uniformly across the river which was similar to findings of CDFG in sampling conducted during the spring of 1950 in the Sacramento River near Red Bluff (Hallock and Van Woert 1959). This latter phenomenon was also demonstrated by USFWS sampling in the Sacramento River near Red Bluff during investigations in 1987 (Vogel et al. 1988).

[1] "Normal" stream flow was not defined by Hallock and Van Woert (1959).

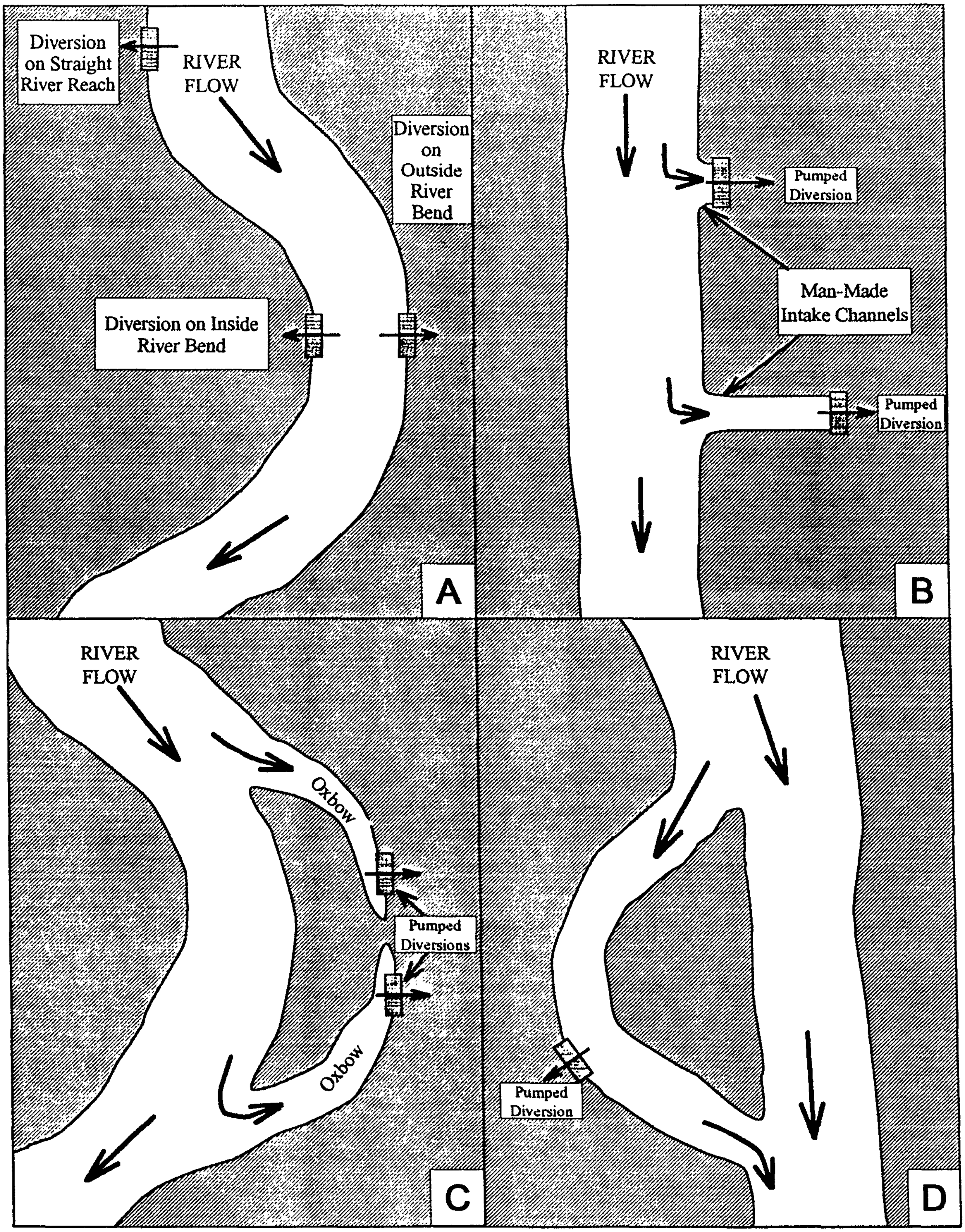



Figure 1. Example variations in locations of riverine diversions. Types B, C, and D can also vary depending on locations on inside bends, outside bends, or straight river reaches.

## Diel Differences in Fish Behavior

USFWS research conducted on the Sacramento River during the 1980s demonstrated that a high rate of young salmon emigration consistently occurred at night. During sampling conducted from January 1982 to July 1987, the USFWS found that the rate of nighttime emigration was approximately twice that of daytime emigration. The annual average proportion of daily emigration occurring during the night ranged from 54 percent to 77 percent (Vogel et al. 1988, Vogel 1989).

## Salmon Downstream Migration Timing

Salmon migrations tend to occur in groups and pulses; these pulses may correspond to increased flow events. For example, USFWS salmon research by Kjelson et al. (1982) and Vogel (1989) reported increased downstream movements of fry chinook corresponding to increase river flows and turbidity, respectively. Sacramento River chinook salmon fry tend to move downstream at the time of seasonal increase in runoff (Hallock and Van Woert 1959). On an overall basis, downstream dispersal of young salmonids could be a function of one or more of the following factors: high velocities, turbidity, search for food (food availability), genetics of the stock, density, chemical constituents, temperature, aggression, competitive interactions, (Vogel 1993b) or natural hydrologic conditions (e.g., type of water year) (Stevens and Miller 1983; Vogel 1989).

In the Sacramento River, there are substantial differences between the downstream migration timing for the four runs of chinook salmon. Figure 2 displays some of the differences in migratory timing of these runs past Red Bluff on the Sacramento River (from Vogel and Marine 1991).

Based on extensive daily monitoring of salmon emigration near Red Bluff during the 1980s, a comprehensive database was developed which revealed interesting aspects of salmon migration from the upper Sacramento River. For example, it was noted that during wet water years, such as that which occurred in 1983, most of the young salmon emigrated from the upper river system early in the year. In contrast, during a dry water year, such as that which occurred in 1985, a large portion of the emigration took place in the spring (Figure 3) (from Vogel 1989).

## Proximity of Diversion to Salmon Rearing Habitat

The long-term biological assessment for the CVP suggested that the greatest losses of young salmon to unscreened diversions may primarily occur in the upper river reaches since during the irrigation season water temperatures in the lower river reaches may cause undesirable (extreme) rearing conditions for salmonids. The presence of young salmon in the lower river reaches may only occur during the later portion of the irrigation season (USBR 1992), presumably because water temperatures become more satisfactory for salmon rearing because of cooler seasonal conditions. The presence of a water diversion in the vicinity of principal salmon rearing habitat could result in significant losses of fish because of their longer period of exposure to the diversion

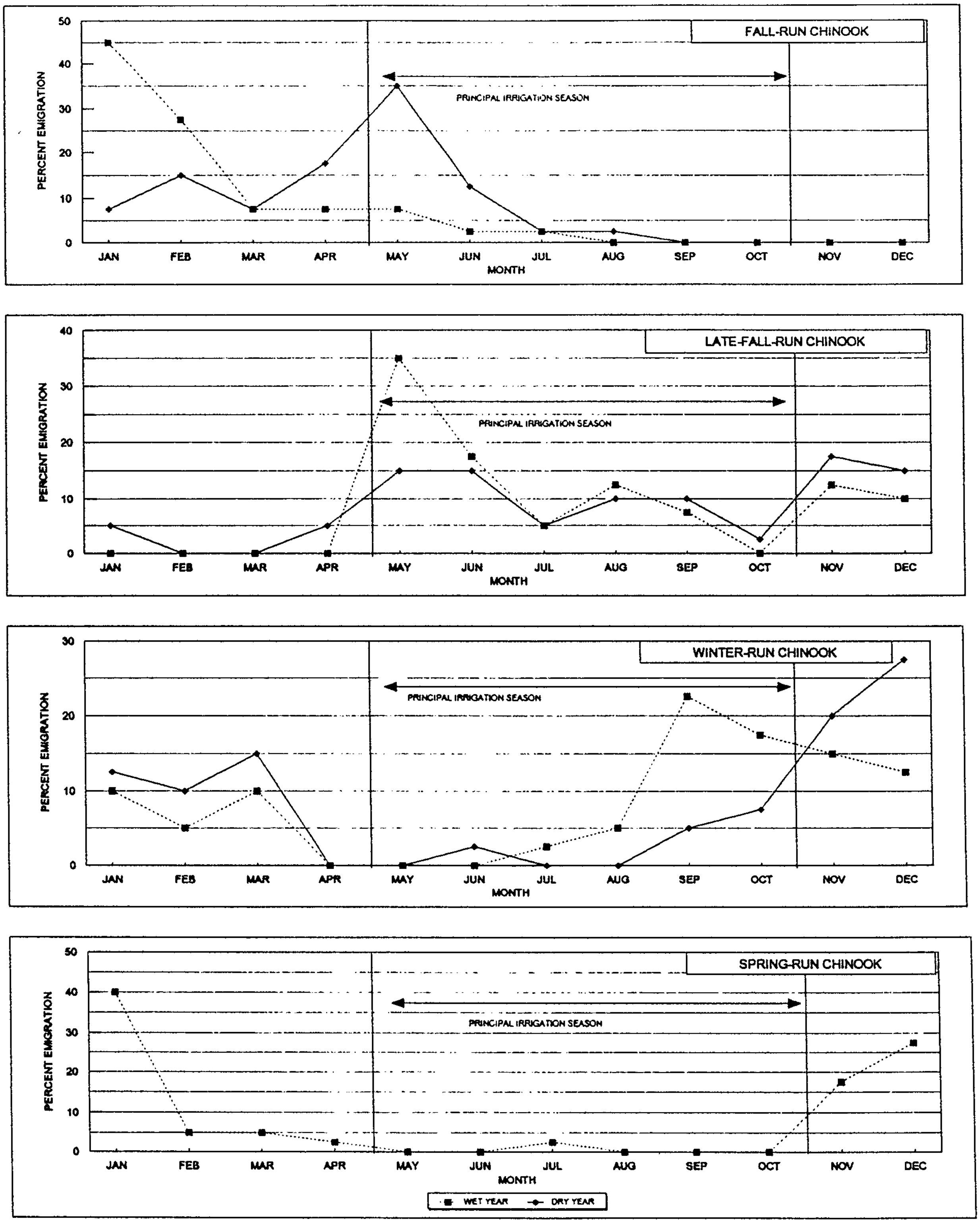
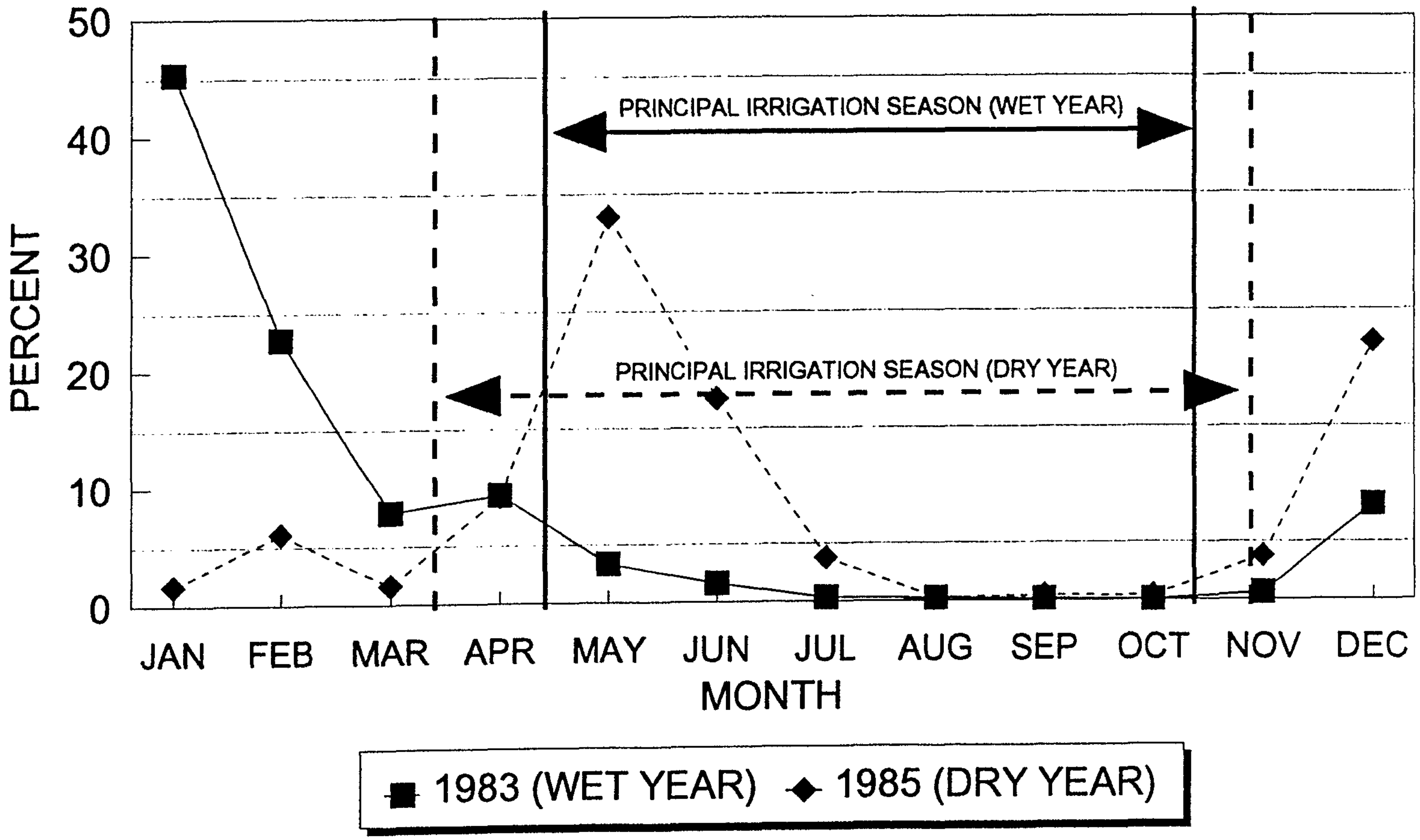



Figure 2. Percent of young chinook salmon which are estimated to have emigrated by mid-month.

Figure 2. Emigration of young chinook salmon past Red Bluff.

FIGURE 3. PROPORTION OF DOWNSTREAM MIGRANT CHINOOK SALMON PASSING RED BLUFF DIVERSION DAM IN THE UPPER SACRAMENTO RIVER DURING A WET AND DRY YEAR



site. The magnitude of losses would depend on the "zone of influence" of the diversion in relation to the specific locality of the rearing habitat.

**Biological Significance of Salmon Life Stage to Population Dynamics of Adult Stock**

The larger juveniles within a particular salmon run can generally be expected to exhibit a higher survival rate than the smaller, younger life phases. The older, larger fish have already been exposed to a multitude of complex density-independent and density-dependent factors which can affect their survival. Reisenbichler et al. (1982) found that the survival rates of young hatchery fish to the adult phase increased substantially with increased size at release from the hatcheries (e.g., fry-sized salmon exhibited a much lower survival rate as compared to smolt-sized or yearling-sized salmon).

**Behavioral Differences between Salmon Life Stages**

Recently hatched salmonids can only tolerate nearly-still water. After emergence from the river gravels, chinook salmon generally select very quiet shallow water over a variety of substrate; as fish grow they continually shift their distribution to deeper, faster water. Salmonid fry are particularly vulnerable at emergence and the initiation of feeding because the fish leave the secure, low-energy environment in the interstices of riverbed gravels and enter the high-energy environment of the river. As fry-sized salmonids grow into larger juvenile-sized fish, they are associated with velocities and depths in proportion to body size, shifting to faster, deeper waters and larger territories (Vogel 1993b).

**Timing of Irrigation Seasons**

Hallock and Van Woert (1959) found that a comparison between the downstream migration timing of chinook salmon and the total volume of water diverted off the Sacramento River (between Redding and Sacramento) showed that during most years the majority of fingerling chinook had moved out of the upper river before the greatest amount of water was diverted for irrigation (Figure 4). The research conducted by the USFWS near Red Bluff demonstrated that the timing of salmon emigration can vary considerably depending on hydrologic conditions which could make the downstream migrants more susceptible to losses in unscreened diversions during dry water years when the irrigation season begins earlier and overlaps considerably with the salmon emigration period (Figure 3).

**Magnitude of Water Withdrawal**

Hallock and Van Woert (1959) believed that the percentage of river flow diverted could be of equal significance with the time when water is diverted in determining salmon losses during the migration period. Hallock (1987) suggested that one technique to estimate the total losses of downstream migrant salmon into unscreened diversions would be based on the percent of the river

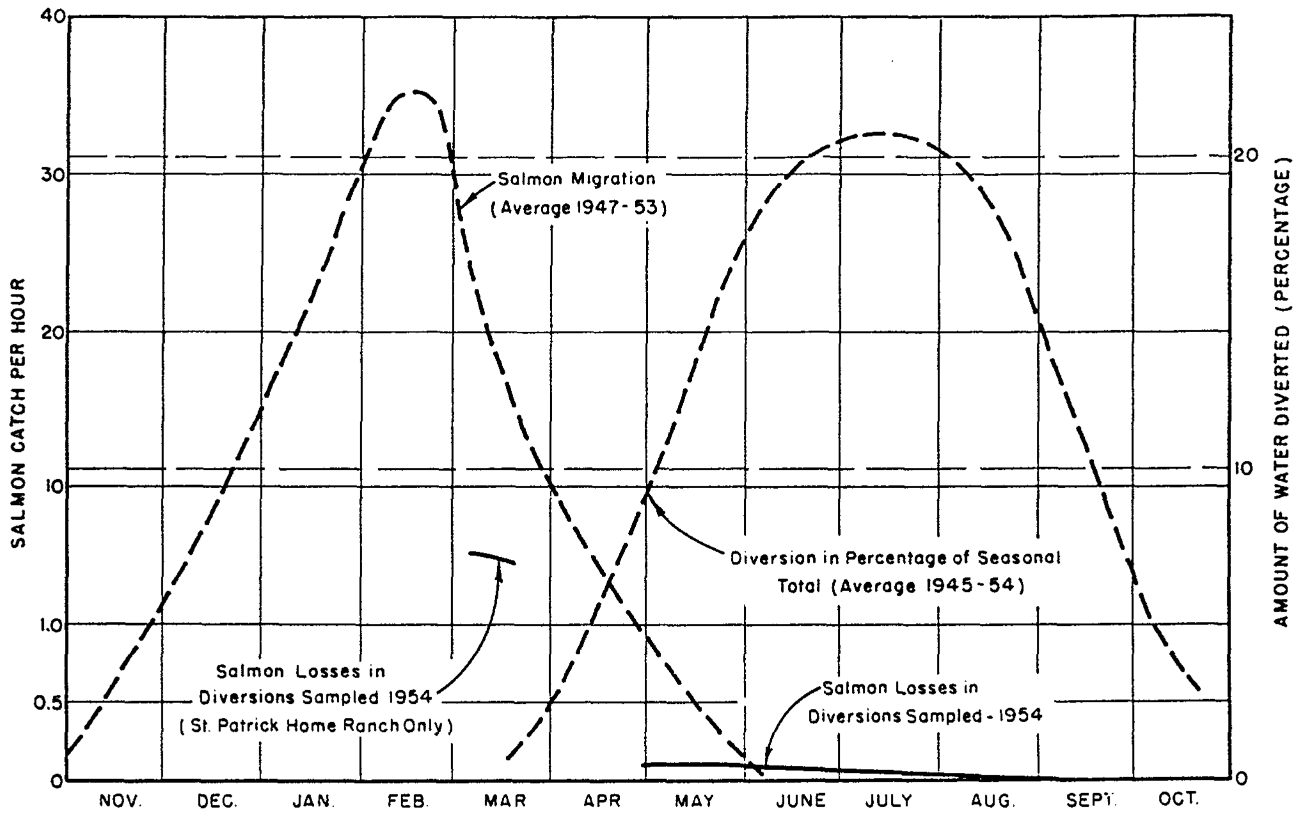



Figure 4. Comparison between times of the seaward migration of Sacramento River chinook salmon fingerlings, their losses in irrigation diversions, and the diversion of water for irrigation. The salmon migration was determined by fyke netting in the Sacramento River at Balls Ferry. Salmon losses were determined by fyke netting in irrigation diversions from the Sacramento River between Butte City and Knights Landing. The average diversion of irrigation water in percentage of the seasonal total includes data for the entire river between Sacramento and Redding. (From Hallock and Van Woert 1959).

flow diverted multiplied by the number of salmonids migrating downstream during the diversion period. If the concentration of fish is higher in diverted water as compared to bypassed water in the river, this technique would understate entrainment losses. Conversely, if the concentration of fish in diverted water is lower than the water remaining in the river, overestimates of entrainment losses would occur. Factors such as the concentration of predatory fish at the diversion site would also influence the magnitude of fish losses.

**Summary**

In summary, the following are important factors to incorporate into methodologies for estimating total losses of fish. Although this list is not intended to be comprehensive, these factors probably encompass the majority of the most important factors which could affect fish losses in unscreened diversions.

- Salmon run (e.g., fall, late-fall, winter, spring)
- Seasonal timing of the water diversion
- Proximity of the diversion to rearing habitat
- Geographic location of the water diversion in the river relative to the proportion of juvenile salmon which would ultimately migrate past the diversion
- Hydrologic conditions preceding the principal downstream migration (e.g., wet or dry water year type)
- Specific life phase of the downstream migrants passing the diversion (e.g., fry versus smolt)
- Physical configuration of the diversion intake and associated facilities
- Location of the diversion intake in the water column
- Concentration of the downstream migrants at various location in the water column and across the river channel
- Diel changes in fish distribution and behavior
- Diel changes in water diversion rate
- Water velocity near the diversion intake
- Water temperature in the vicinity of the diversion intake
- Location of the diversion intake in the river channel (e.g., oxbow, inside or outside bend, set back or on the river, etc.
- Absence or presence and concentration of predatory fish at the diversion site

**Monitoring Programs to Evaluate Actions to Reduce Fish Losses at Diversions**

Monitoring screened water diversions will be valuable to ensure the screening programs are biologically effective. However, it would probably not be feasible to conduct extensive evaluations at every diversion screened to minimize or eliminate fish mortality. Depending on the site-specific considerations at the diversion facility, it is conceivable that such evaluations could be more costly than the original cost to screen the water diversion. However, some evaluations will be necessary to ensure the fish protection programs are serving their intended purpose. Additionally, it is likely that evaluations will yield useful scientific information to continually improve upon fish protection facilities (i.e., learning from successes and failures).

The USBR is presently developing a monitoring program to evaluate the effectiveness of recent fish screening projects on the Sacramento River. This program is in accordance with the NMFS Biological Opinion Take Statement concerning Central Valley Project Operations effects on winter-run chinook salmon which required that USBR "...evaluation programs for all demonstration screening sites must be developed and implemented." The principal focus of these assessments is to determine potential entrainment past the newly installed screens (Spencer Hovekamp, USBR, Redding, CA, pers. comm.).

Monitoring potential entrainment of fish past a screening facility is probably the easiest aspect of screening effectiveness to evaluate. Depending on site-specific considerations, netting, electrofishing, or utilization of some other technique for fish capture can be employed on the downstream (inward) side of the screening facility. Potential problems with sampling gear avoidance, secondary losses to predation, and other factors should be considered to ensure meaningful results. Fish sampling devices should be located as close as possible to the screen to overcome such problems as secondary and undetected losses to piscivorous fish or birds.

Evaluating potential fish losses attributable to predation in the vicinity of the screening device or physical injury on the screen would be the most difficult factors to evaluate at new fish screens. Techniques such as fish mark/recapture, radiotelemetry, underwater videography, and other relatively sophisticated methods can be employed but can be time consuming and expensive. Site-specific considerations should dictate the need to conduct such extensive evaluations. For example, certain water diversion sites may be known to harbor high concentrations of predatory fish in the vicinity of the screened intake or fish bypass outfall. The magnitude of water withdrawal relative to the numbers of fish exposed to the screening facility may warrant intensive field evaluations to ensure the facility is functioning as intended. Depending on environmental conditions present at the site (e.g.,water clarity), underwater video monitoring systems could be particularly valuable to ascertain potential problems with impingement or predation.

In instances when all fish protection devices cannot be evaluated (due to cost or some other reason), monitoring programs could be developed by sampling representative sites stratified according to the most relevant variables of concern. For example, sampling programs could be designed to monitor only certain sites which would be stratified (categorized) according to such variables as diversion type, screen type, magnitude of water withdrawal, geographic location in the river system, or many of the other factors previously discussed.





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## References

Big Eagle, J.D., K. Brown, and J.P. Bigelow. 1993. Survival and condition of juvenile salmonids passing through the downstream migrant fish protection facilities at Red Bluff Diversion Dam on the Sacramento River, Spring 1993. Progress Report. USFWS Report No. AFF1-FRO-93-10. November 1993. 29 pp.

Brown, L.R. and P.B. Moyle. 1981. The impact of squawfish on salmonid populations: A review. North American Journal of Fisheries Management 1:104-111.

California Department of Fish and Game. 1919. Reply to the Eden Resolution by the executive officer of the Fish and Game Commission. Calif. Fish Game 5:184.

California Department of Fish and Game. 1990. Central Valley Salmon and Steelhead Restoration and Enhancement Plan. April 1990. 115 pp.

California Department of Fish and Game. 1993. General fish screening criteria. February 1993. 2 pp.

California Department of Fish and Game. 1994. Fish screening policy. March 9, 1994.

California Department of Fish and Game. 1994. Fish Screen Action Plan. June 6, 1994. 15 pp.

Cramer, S.P., D. Demko, C. Fleming, and T. Loera. 1990. Survival of juvenile chinook at the Glenn-Colusa Irrigation District's Intake. Progress Report, April-July 1990. Glenn-Colusa Irrigation District. 91 pp.

Cramer, S.P., D. Demko, C. Fleming, T. Loera, and D. Neely. 1992. Juvenile chinook passage investigations at Glenn-Colusa Irrigation District Diversion. 1991 Annual Report to Glenn-Colusa Irrigation District. 170 pp.

Cramer, S.P. and D. Demko. 1992. Evaluation of juvenile chinook entrainment at six unscreened water diversions along the Sacramento River by RD 108. S.P. Cramer & Associates, Inc. Annual Report 1992.

Cramer, S.P., E.S. Van Dyke, and D.B. Demko. 1994. Evaluation of sound and electrical fish guidance systems at the Wilkins Slough Diversion operated by Reclamation District 108. S.P. Cramer & Associates, Inc. Annual Report 1993. March 1994.

Decoto, R.J. 1978. 1974 evaluation of the Glenn-Colusa Irrigation District fish screen. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report No. 78-20. September 1978. 18 pp.

Decoto, R.J. 1979. 1975 evaluation of the Glenn-Colusa fish screen facility. California Department of Fish and Game, Anadromous Fisheries Branch. Unpublished office report. 20 pp.

Fisher, F.W. 1976. Limited evaluation of the Woodbridge Irrigation District fish screen. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report No. 76-10. August 1976. 7 pp.

Garcia, A. 1989. The impacts of squawfish predation on juvenile chinook salmon at Red Bluff Diversion Dam and other locations in the Sacramento River. U.S. Fish and Wildlife Service Report No. AFF/FAO-89-05. 35 pp.

Hall, F.A. 1977. A discussion of Sacramento squawfish predation problems at Red Bluff Diversion Dam. Memorandum to predation study files. Bay-Delta Fishery Project. California Department of Fish and Game. 14 pp.

Hallock, R.J. 1980. Returns from steelhead trout, *Salmo gairdneri*, released as yearlings at Coleman Hatchery and below Red Bluff Diversion Dam. California Department of Fish and Game. Anadromous Fisheries Branch Office Report. 3 pp.

Hallock, R.J. 1983. Effects of the Red Bluff Diversion Dam on chinook salmon, *Oncorhynchus tshawytscha*, fingerlings. California Department of Fish and Game. Anadromous Fisheries Branch Office Report. 8 pp.

Hallock, R.J. 1987. Sacramento River salmon and steelhead problems and enhancement opportunities. A report to the California Advisory Committee on Salmon and Steelhead Trout. June 22, 1987. 92 pp.

Hallock, R.J. and W.F. Van Woert. 1959. A survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin Rivers. Calif. Fish and Game 45:227-296.

Hanson, C.H. and H.W. Li. 1983. Behavioral response of juvenile chinook salmon, *Oncorhynchus tshawtscha*, to trash rack bar spacing. Calif. Fish and Game 69:18-22.

Hayes, D. 1994. Fish facility programs and developments in northern California. May 1994 memorandum from Darryl Hayes, California Department of Water Resources, Environmental Services Office. 9 pp.

Johnson, R.R. and S.J. Croci. 1994. Entrainment evaluation of the Red Bluff Diversion Dam downstream migrant fish protection facilities, May-October 1993. U.S. Fish and Wildlife Service Report No. AFF1-FRO-94-05. March 1994. 9 pp. and appendices.

Kano, R.M. 1987. The effects of trashrack and bypass design and predator control on predation losses of juvenile salmon at Hallwood-Cordua fish screen. California Department of Fish and Game. Technical Report 14. FF/BIO 4ATR/87-14. November 1987. 17 pp.

Kjelson, M.A., P.F. Raquel, and F.W. Fisher. 1982. Life history of fall-run juvenile chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin estuary, California. Salmon in Estuaries. pp. 393-411.

McGregor, E.A. 1922. Migrating salmon at the Redding Dam. Calif. Fish and Game 8:141-154.

Moyle, P.B. 1976. Inland Fishes of California. University of California Press. Berkeley, California. 405 pp.

National Marine Fisheries Service. 1993. Advance notice of proposed rulemaking concerning screening water diversions to protect Sacramento River winter-run chinook salmon. Federal Register, Volume 58, No. 199 (58 FR 53703). October 12, 1993.

Phillips, J.B. 1931. Netting operations on an irrigation canal. California Fish and Game 17:45-52.

Quelvog, B.D. 1981. An inventory of selected fish screens in California. Calif. Dept. Fish and Game, Anad. Fish. Br. Admin. Rep. No. 81-5. 7 pp. plus appendices.

Reading, H.H. 1982. Passage of juvenile chinook salmon, *Oncorhynchus tshawtscha*, and American shad, *Alosa sapidissima*, through various trashrack bar spacings. Interagency Ecological Study Program for the Sacramento - San Joaquin Estuary. Technical Report No. 5. FF/BIO-4ATR/82-5. October 1982. 10 pp.

Reisenbichler, R.R., J.D. McIntyre, and R.J. Hallock. 1982. Relation between size of chinook salmon, *Oncorhynchus tshawytscha*, released at hatcheries and returns to hatcheries and ocean fisheries. Calif. Fish and Game 68:57-59.

Resources Agency of California. 1989. Upper Sacramento River Fisheries and Riparian Habitat Management Plan. 158 pp.

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:448-458.

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and Delta smelt in the Sacramento-San Joaquin River system. N. Amer. J. Fish. Mgmt. 3:425-437.

U.S. Bureau of Reclamation. 1992. Biological assessment for U.S. Bureau of Reclamation long-term Central Valley Project operations criteria and plan. U.S. Bureau of Reclamation, Mid-Pacific Region, Sacramento, California. October 1992.

U.S. Bureau of Reclamation. 1993. Final environmental assessment and finding of no significant impact, Red Bluff Diversion Dam Pilot Pumping Plant Program. Mid-Pacific Region, Sacramento, California. August 1993. 41 pp. and appendices.

U.S. Bureau of Reclamation. 1994. Schedule for submission of study plans for biological evaluation of research pumping plant. 1 pp.

U.S. Fish and Wildlife Service. 1993. Annual report fiscal year 1993, Northern Central Valley Fishery Resource Office, Red Bluff, California. 29 pp. and appendix.

Vigg, S. 1988. Functional response of northern squawfish predation to salmonid prey density in McNary tailrace, Columbia River. Pages 174-207 In T.P. Poe and B.E. Rieman (editors). Predation by resident fish on juvenile salmonids in John Day Reservoir. Volume 1, Final Report of Research 1983-1986. Bonneville Power Authority.

Vigg, S., T.P. Poe, L.A. Pendergast, and H.C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Vogel, D.A. 1989. Tehama-Colusa Canal Diversion and Fishery Problems Study. Final Report. U.S. Fish and Wildlife Service Report No. AFF/FAO-89-06. April 1989. 33 pp. with appendices.

Vogel, D.A. 1992. Assessment of the fish passage facilities at Lake Lodi in the Mokelumne River. Vogel Environmental Services. September 1992. 42 pp.

Vogel, D.A. 1993a. Need for updating fish protection facilities for anadromous and resident stocks in the west coast of North America. Fish passage policy and technology. Proceedings of the American Fisheries Society Bioengineering Symposium, Portland, Oregon. August 30 - September 3, 1993. p. 69-74.

Vogel, D.A. 1993b. Chinook salmon rearing in the Central Valley. Abstract in Notes and Selected Abstracts from the Workshop on Central Valley Chinook Salmon. University of California, Davis. January 4-5, 1993. 2 pp.

Vogel, D.A., K.R. Marine, and J.G. Smith. 1988. Fish Passage Action Program for Red Bluff Diversion Dam. Final Report of Fisheries Investigations. U.S. Fish and Wildlife Service Report No. FR1/FAO-88-19. 77 pp. plus appendices.

Vogel, D.A., K.R. Marine, and J.G. Smith. 1990. A summary of upstream and downstream anadromous salmonid passage at Red Bluff Diversion Dam on the Sacramento River, California, U.S.A. Proceedings of the International Symposium on Fishways '90 in Gifu, Japan, October 8-10, 1990. p. 275-281.

Vogel, D.A. and K.R. Marine. 1991. Guide to Upper Sacramento River chinook salmon life history. Prepared for the U.S. Bureau of Reclamation, Central Valley Project. 55 pp. with appendices.

Vogel, D.A. and K.R. Marine. 1994. Evaluation of the Downstream Migration of Juvenile Chinook Salmon and Steelhead in the Lower Mokelumne River and the Sacramento-San Joaquin Delta (January through July 1993). Vogel Environmental Services. April 1994. 59 pp. with appendices.

Vondracek, B. and P.B. Moyle. 1983. Squawfish predation at Red Bluff Diversion Dam. Contract report for the California Department of Water Resources. 34 pp.

Vondracek, B. 1987. Digestion rates and gastric evacuation times in relation to temperature of the Sacramento squawfish, *Ptychocheilus grandis*. Fishery Bulletin 85:159-163.

Vondracek, B., S.R. Hanson, and P.B. Moyle. 1990. Sacramento squawfish predation on juvenile chinook salmon below a diversion dam on the Sacramento River. Unpublished Manuscript. (Acquired from P.B. Moyle). 29 pp.

Ward, P.D. 1989. A review and evaluation of the losses of migrant juvenile chinook salmon at the Glenn-Colusa Irrigation District. California Department of Fish and Game, Glenn-Colusa Fish Screen. Unpublished office report. 35 pp. and six appendices.